APPLICATION OF ANALYTIC HIERARCHY PROCESS FOR RANKING SOLID WASTE MANAGEMENT OPTIONS

by

URMILA BENIWAL

Department of Civil Engineering

Indian Institute of Technology Kanpur

July, 1997

APPLICATION OF ANALYTIC HIERARCHY PROCESS FOR RANKING SOLID WASTE MANAGEMENT OPTIONS

A Thesis Submitted
in Partial Fulfillment of the Requirements for the
Degree of Master of Technology

by

URMILA BENIWAL

to the

Department of Civil Engineering
Indian Institute of Technology Kanpur
India

July, 1997

CERTIFICATE

It is certified that the work contained in the thesis titled *Application of Analytic Hierarchy Process for Ranking Solid Waste Management Options* by Urmila Beniwal has been carried out under my supervision

Dr Vinod Tare
Professor
Department of Civil Engineering
Indian Institute of Technology Kanpur
KANPUR - 208016

July, 1997

ACKNOWLEDGMENTS

I wish to express my deep sense of gratitude and sincere regards to my thesis supervisor, Dr Vinod Tare for his constant inspiration, affectionate guidance and encouragement throughout the course of my work I feel indebted to him for giving me those extra minutes of friendly help

My sincere thanks are due to all my batchmates and juniors, who have helped me in every stage of my work I am particularly thankful to Manoj, Manas and Saurabh for their valuable help Finally I would like to thank all my friends who have made my stay at I I T K a memorable one

Urmila Beniwal

CONTENTS

LIST OF FIGURES

Figure **Caption**

LIST OF TABLES

ABSTRACT

With rapid growth of industrialisation and urbanisation, one of the major pollution problems of cities has been the disposal of solid wastes There is voluminous information available on technologies associated with all the constituents of solid waste management system, namely storage, collection, transportation, processing and disposal However in India, it is very common to find solid waste lying here and there in an environmentally unsound manner, causing obnoxious conditions This thesis provides an analysis of solid waste management system of Jaipur city, considered as representative of urban centers in India The analysis of the problems associated with a solid waste management system illustrated that thrust area of solid waste management system should be storage, collection and transportation of the wastes rather than processing and disposal and also that solutions involve complex interdisciplinary relationship among fields such as political science, economics, public health, sociology, conservation as well as engineering As such solid waste management policy involves multi criteria decision making Analytical Hierarchy Process (AHP) was used to develop a methodology to rank solid waste management alternatives, by considering all factors, conflicting as well as equally important, associated with solid waste management and finding an optimum trade off between them

Key words: Solid waste, Analytic Hierarchy Process (AHP), Environmental Considerations, Management

1. PROLOGUE

Rapid growth of population, industrialisation and urbanisation in the later half of the twentieth century has resulted in increase in environmental pollution Out of various sources of pollutants, solid waste constitutes a major share towards environmental degradation Solid wastes may arise from human and animal excreta or domestic, industrial and commercial wastes Pathogenic organism present in human and animal wastes cause spreading of communicable diseases One of the recent example is suspected plague epidemic due to unhygienic conditions caused by accumulation of solid wastes in Surat, Gujarat The putrescible matter present in these wastes gets decomposed causing obnoxious conditions besides spoiling the quality of land and water environment The problem of solid waste disposal both from domestic and industrial sources has become very acute in towns and cities as the development of disposal facility has not kept pace with the quantum of generation of wastes It is, therefore, a common sight to find solid wastes dumped in a haphazard manner in every nook & corner of the cities

Solid waste management is a discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics and other

environmental considerations, and that is also responsive to public attitudes In its scope, solid waste management includes all administrative, financial, legal, planning and engineering functions involved in the whole spectrum of solutions to problems of solid wastes thrust upon the community by its inhabitants The solution may involve complex interdisciplinary relationships among such fields as political science, city and regional planning, geography, economics, public health, sociology, conservation as well as engineering and material science

Considerable work has been done, both in terms of research and practice, on various aspects of the solid waste problems and voluminous information is available on various technologies associated with collection, storage, transfer, transport, characterization, processing, reuse Much of this is available in standard text books and reports of various government and non government organisations Significant portion of the funds of various agencies responsible for management of urban centers is allocated for solving problems associated with solid wastes However most of the cities, particularly in India, are very far from adopting the environmentally sound practice of handling solid wastes It is with this concern that the present work was initiated to analyze various issues in solid waste management, starting from its generation to final disposal considering socio-economic aspects along with concerns for adopting available technological solutions under Indian conditions The studies are carried out through a case study for handling of solid wastes of Jaipur city in Rajasthan

2. MANAGEMENT OF MUNICIPAL SOLID WASTE: AN OVERVIEW

2.1 GENERAL

Solid wastes are non liquid waste material which are generated from domestic, trade, commercial, industrial, agricultural and mining activities as well as also from the public services WHO (1984) has defined solid waste as "matter in the wrong place" which implies that a material becomes waste only when a specific owner ceases to have a use for it Printer and Roberts (1987) defined waste as any material which is rejected by the holder as no longer having any value Municipal solid waste is the waste generated in residential, commercial & institutional area

Solid waste has three main characteristics, weight, density and constituents or composition (WHO, 1984) These characteristics of the waste generated in urban areas depend upon a number of factors such as food habits, standard of living, degree of commercial & industrial activities, etc No rational decision on solid waste management systems are possible until data of these characteristics are available.

2.2 SOLID WASTE MANAGEMENT

The first objective of solid waste management is to remove discarded materials from inhabited places in a timely manner to prevent the spread of disease to minimize the likelihood of fires and to reduce aesthetic insults arising from putrefying organic matter The second objective, which is equally important, is to dispose of the discarded materials in a manner that is environmentally acceptable Decision to be made in solid waste management policy formation must be made in four basic areas collection, transportation, processing and disposal

2.2.1 Collection

The collection and removal of municipal solid waste has been given less attention than this function deserves The efficient collection of municipal solid waste consists of providing a proper service in a sanitary, dependable and economical manner The effectiveness of collection system and the cost of the operation depend to a great extent on the cooperation of the house holders in preparing and storing the refuse in accordance with regulations In United States of America collection costs generally account for 70-85% of total solid waste management costs and labour represents 60-75% of collection cost (Mackenzie and Cornwell,1991) At one extreme the waste may be carefully separated by classes and at other extreme, all refuse may be dumped without discrimination In the latter case recovery of the resources is

very difficult if not impossible and also nuisance and the menace to public health is much more

The separation of the waste by classes can be done prior to collection or after collection The former is a better practice as it involves the generator of the waste, and is much more hygienic and efficient Proper storage of waste is a prerequisite for an efficient collection system Followings are the options for storage

1 Individual waste storage containers
2 Communal waste storage containers
3 Communal waste storage containers with chutes
4 Bulk waste storage containers

For individual domestic dwellings the means of collecting waste may be from the individual houses or from a communal storage container sited some distance away. The use of disposable plastic or paper sack system is considered to be a better alternative to the ordinary dustbin as being more hygienic method of storage (Higginson, 1983) An expendable sack system evolved providing for either a paper or plastic sack being attached to a metal frame or used as a bin liner inside the type of bin in use The sacks can be made of various colours of different thickness and sizes with printed instructions so that storage of refuse, removal of salvage materials or trade waste can be easily organized by colour selection

The disposable sack system may cost more in financial terms though there are substantial economies made in labour and use of vehicles, but the cost may be

justified for amenity reasons such as improved methods of storage, better hygiene and flexibility in collection with quietness an added advantage (Higginson, 1983) The choice of the size of the containers or sacks depends upon house hold density, social habits and frequency of collection

In a city, there are a considerable number of dwellings in residential blocks of varying number of storeys Communal waste storage containers with chutes may be installed in medium to high rise buildings The present capital cost for the pipeline installation of pneumatic conveyors of waste is a deterrent for local authority in times of financial restrictions

For disposal of putrescible kitchen waste, individual sink grinders and Garchey system use the kitchen sink outlet for the removal of waste Sink grinders increase the consumption of water and place an additional load on the drainage and sewage disposal plant Owing to their limitation in handling other components of domestic waste they will make little future difference to the collection service In catering establishments for the prompt removal of food waste, food waste disposers are frequently installed These machines are heavy duty specially designed to handle all kinds of waste, grinding them into almost liquefied form and discharging direct into the drainage system Whatever facilities are contemplated, they must be adequate in size and space, have maximum convenience for tenants and collectors, be hygienic, safe from fire risk and soundly insulated

2.2.2 Transportation

The methods of carriage are many and varied, whether to use one or more or indeed any of them will be determined mainly in the end by economics Conservation of fuel is an important aspect to be considered and therefore economic viability of compaction of waste prior to its carriage should be found out For carriage of waste the alternatives are by roads, rails or water

Road

The road method of carriage is an everyday occurrence to us For an efficient road carriage method route selection is an important criterion to be considered other than selection of a suitable vehicle Route selection implies average haulage distance and travel time which depends on the degree of traffic on the selected route Selection of a suitable vehicle implies the size of the vehicle and facilities to load and unload the waste

Rail

It is useful for movement of bulk waste over very large distances of the order of 150 KM or more It is under these circumstances that the use of rail haulage starts to show dividends, provided a large enough volume of waste is generated in an area that itself is small enough to allow disposal there itself The disposal site needs to be able to absorb the large volumes of waste transported to atleast 10, and in reality nearer to 20 years to ensure full economic use of the plan (Harrison, 1983)

Water

The rubbish moved down river is merely shot into barges and tamped down It is grabbed out of the barges by grab crane at the disposal sites (Harrison, 1983) In Finland and Sweden, use of small boats to collect rubbish from island homes prior to depositing the rubbish in a compactor for onward transmission to disposal is also reported (Jaakkoo, 1980)

2.2.3 Processing & Disposal

There are a number of established methods available for processing and disposal of solid waste These are-

1 Sanitary land fill
2 Composting
3 Anaerobic digestion
4 Vermiculture
5 Incineration/Pyrolysis

Before deciding on the methods of final disposal, most important pre-requisite is the collection and transportation of solid waste to a pre- determined site

Sanitary Landfill

The disposal of municipal solid waste in a well managed land adopting scientific methods of operations is termed as sanitary land filling The most important and general aspect relating to landfill is identification of a suitable site Landfill programme is a very time consuming process and careful

operations are needed through out the period. The method can be practiced where large area of land is available or land is to be reclaimed which otherwise is likely to be abandoned after carrying out specific operations

Composting

Composting is probably the oldest form of waste disposal It is defined as the decomposition of heterogeneous organic matter by a mixed microbial population in a moist, warm, aerobic environment Composting is considered to be a mean of accelerating the natural process in which micro- organisms convert organic waste into a product of significant value to agricultural farming

Composting is an ancient art, the scientific principles of which are now being more fully understood and successfully applied to refuse disposal Nature provides a great tolerance to enable a wide range of organic materials to be degraded by micro-organisms and given certain easily attained operating conditions, the risk of failure is low

Anaerobic Digestion

Anaerobic digestion is the process most frequently used for biological decomposition of organic wastes both domestic and industrial loaded with high concentration of organic matter in the absence of oxygen In the process, organic wastes are hydrolyzed, liquefied and gasified As a result, a well mineralized residue is obtained The gases liberated are used for fuel and

lighting The mineralised residue can be used as a manure There is an appreciable saving in recurring costs because of the utilisation of the bio gas

Indian garbage can be effectively digested only after proper blending with several treatment plant sludges, in order to adjust the carbon nitrogen ratio and so the cost of the compost production is several times higher than the conventional manure used by farmers (CPCB, 1994)

Vermiculture

It is an innovative type of biotechnology in which earthmovers are effectively employed to maximize the growth of aerobic bacteria for waste processing The ecosystem components are soil, roots of the plant, bacteria and earthmovers Vermiculture most attractive feature is that it combines soil processing with waste processing When bio-degradable wastes are applied to a soil containing earthmovers, simple wastes like sugars are consumed directly by bacteria nurtured by earthmovers Complex wastes are first broken down into simpler compounds by enzymes produced by earthmovers, before fed to the bacteria

Vermiculture has been demonstrated on diverse organic residues generated in agriculture, cities, agro processing, food and biotechnology industries It is seen that vermiculture generated 100-1000 time higher value addition as compared to the conventional techniques of composting, vermicomposting and biomethanation (Bhawalkar, 1995)

Incineration/Pyrolysis

Incineration is used mainly as a mean of achieving maximum volume reduction of the solid waste It is a fairly costly method of disposal The incineration process is favoured when there is acute scarcity of land available In recent years much research has been undertaken into incineration of refuse under oxygen deficit conditions and this process is called pyrolysis The objective of pyrolysis of refuse has generally been to produce a gas which could be stored and used when advantageous, whereas it is not practicable to store the energy recovered from normal incineration of refuse A major disadvantage of pyrolysis is that design developed so far have not been able to take in crude refuse as do large incinerators and the cost of producing a prepared material suitable for pyrolysis is considerable

2.3 SELECTION OF TECHNOLOGY FOR SOLID WASTE DISPOSAL

With the poor developing communities with chronic problems and very limited resources in India still the management of solid waste can be done to keep environs clean Because of the financial constraints and other associated problems, it becomes very important to adopt the most economically viable method for solid waste disposal Therefore, all the technologies must be studied and scrutinised before arriving at final decision For facilitating to take decision the merits and demerits of disposal methods are given in Table 2 1

It appears that in countries like India, composting seems to be the most ideal However, it does not mean that this method needs to be necessarily followed If situation so warrants and depending upon fund availability and taking local situations into considerations, the other options may also be tried

2.4 RECYCLING

Recycling is a mode of solid waste utilisation which helps in reducing the quantum of waste and conserves material resources Innovative technolog- ies have been developed for recycling of the material segregated from solid waste The emphasis of late is on minimisation and recycling of waste along with proper disposal methods

Detailed examinations of economics has produced general agreement that revenues from the recovered product can, at best reduce overall disposal costs Benefits, such as employment and community development may not be directly linked to the aim of resource recovery, but are nevertheless important as considerable scope exists for developing reclamation centers adopting to local conditions Reclamation of any sort, apart from being a commercial activity, has a wider value in terms of conservation of the earth's non-renewable resources

Table 2 1 : Various Waste Disposal Methods with their Merits and Demerits

Method of waste disposal	*Demerits*	*Merits*
Land Filling	. Restricted site availability, cannot last longer . Pollutes water sources . Anerobic gas production explosion	Easy operation . Land gets levelled
Open Land Dumping	Environment pollution . Costly large area occupied . Ugly look to cities and surroundings smoke and fire . Shifting of location due to space becoming full	. Lower initial cost Non skilled job
Incineration	. Smoke and gaseous as well as particulate pollutants are emitted . Temperature rise Costs higher . Capacity for incineration is a constraint	. Standard hygienic operation . Maximum volume reduction is achieved
Biodegration	. Success is heavily dependent on the composition of the waste and C/N ratio	. Highly useful product for land improvement and for crop production

Proper separation of different materials from solid waste is a pre-requisite to recycle and so segregation of the waste needs to be attended to by the authorities In India ragpickers are doing it very effectively but unfortunately it is encouraging child labour problem which is already very acute in our country

2.5 PROBLEMS RELATING TO URBAN SOLID WASTE MANAGEMENT

Management of waste generated within the city is the responsibility of the local authorities, while those generated by industry is that of the generator The following are some of the common causes of indiscriminate disposal by industries and the municipal bodies

1 Low priority for safe disposal
2 Lack of appropriate organisation
3 Lack of financial resources and technical manpower
4 Lack of proper disposal sites and knowledge of disposal methodologies

2.5.1 Problems Faced By Municipal Bodies

Surface and manual disposal of wastes is the most widely practiced system of waste disposal in Indian cities Lack of an established system for collection,

transportation and disposal and complete networking of the system is the major constraint for proper disposal The local bodies which are responsible for proper disposal of urban waste are over burdened and have additional responsibilities of much higher priorities like immunisation, food sample listing, street cleaning, etc and waste disposal is relegated to the end of list Where it has been possible to establish disposal system, these are not operated and maintained properly The reasons for poor operation and maintenance are-

1 Inadequate finances
2 Inadequate training of personnel
3 Lack of performance monitoring
4 Inadequate emphasis on preventive maintenance
5 Lack of management and
6 Lack of appreciation of the importance of the facility by the community, etc

3. OBJECTIVE AND SCOPE

Solid waste management is an interplay of various components Substantial amount of work is done for developing technologies for every component of the solid waste management But there is a need for an integral approach, adaptable to local conditions as efficient functioning of a disposal system very much depends on storage, collection and transportation system

Other than technology many other factors are also associated with solid waste management like economics, social impact, environmental consideration, etc Resource conservation also need to be considered seriously as realisation of the limits of our natural resources is increasing

Solid waste management involves a set of conflicting and equally important parameters, quantitative as well as qualitative To make a policy, an optimum trade off between these parameters needs to be obtained. The Analytic Hierarchy Process (AHP) provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent and independent qualitative and quantitative information The principal objective of the present study is to illustrate the application of AHP to address a complex problem of ranking options for solid waste management and finding out the most suitable of them all

In the present study, a case study was undertaken to illustrate the real fate of the municipal solid waste from generation point to disposal point followed by developing a suitability index for ranking options for solid waste management The scope of the work can be summarized as -

1 Collection of data of municipal solid waste of Jaipur city
2 Analysis of the data
3 Identification of factors associated with solid waste management and formation of various hierarchy levels
4 Evaluation of relative importance of these factors at each hierarchy level by assigning weightages and its successive progression from lowest to highest level of hierarchy
5 Development of suitability index

4. A CASE STUDY : JAIPUR CITY

4.1 STUDY AREA

Jaipur, the capital of state of Rajasthan is located between 26° 45'N & 27° 10'N latitude and 75° 30'E & 75°5'E longitude It is situated at 427-457m above mean sea level The area of the city is about 385 sq km

Jaipur city is one of the fastest growing cities of India The population figures for the last 100 years show that there had been many fluctuations in the first fifty years However, it showed a steady rise from 1921 to 1941 and sudden increase from 1941 to 1991 accounting for about a tenfold increase in a span of 50 years only According to 1991 census the population of city was 16,27,836 and in 1996 it is approximated to be 22,00,000

Meteorological studies of Jaipur city show that the city falls within a semi arid area of Rajasthan subjected to extreme conditions of weather with very hot summers, cold winter and moderately low rainfall Climatologically a year is distinctly divided into three seasons i e summer, winter & monsoon The highest temperature reached during summers is more than 45°C and the lowest is less than 10°C during winters

4.2 MUNICIPAL CORPORATION : A PROFILE

Municipal corporation, Jaipur is the agency responsible for solid waste management of the city and is headed by an elected Mayor assisted by Deputy Mayor, Chairman, Health & Sanitation Committee, Chief Works Officer The incharge of each zone is a commissioner who is assisted by a Health Officer and a Chief Sanitary Inspector Like wise each ward is headed by a Sanitary Inspector assisted by supervisor, jamadars, etc (Figure 4 1)

Out of 385 sq km area of Jaipur city, 218 30 sq km area comes under the *purview of Municipal Corporation , Jaipur From the management &* administrative point of view, it is divided into six zones which are further divided into 70 wards (Table 4 1) Each ward is divided into many beats

4.3 FUNCTIONAL ELEMENTS OF SOLID WASTE MANAGEMENT

4.3.1 Collection

A three tier scheme is being used for collection of the solid waste Collections from individual house is not practiced The present collection system can be described as community described as community bin system

Table 4.1 Ward-wise Population Distribution of Jaipur City

Name of the Zone	No of Wards	Ward Nos	Population
Moti Doongari	10	18, 26, 27, 29, 30, 31, 33, 34, 35	3,09,915
Hawa Mahal, East	12	44, 45, 46, 47, 48, 49, 50, 51, 52, 55, 56, 57	3,81,978
Hawa Mahal, West	11	39, 49, 41, 42, 43, 53, 54, 58, 59, 60, 61	3,57,983
Civil Lines	14	2, 3, 4, 5, 6, 7, 11, 15, 16, 17, 19, 20, 21, 38	4,33,518
Vidhyadhar	15	1, 8, 9, 10, 36(A), 36(B), 37, 62, 63, 64, 65, 66, 67, 68, 69, 70	4,70,785
Sanaganer	8	12, 13, 14, 22, 23, 24, 25, 28	2,45,821

* Extrapolated from 1991 census data with 37 5 % growth rate

The smallest unit 'beat' is cleaned by 3 workers One of the workers sweeps roads/streets and accumulates the waste in small heaps One of the workers cleans the drains and accumulates the waste The third sweeper removes the heaped waste as well as empties the community bins, if any and takes to the garbage collection depot in a hand cart. Generally, each ward has 8-10 garbage collection depots In Jaipur city there are 922 such depots recognized by Municipal Corporation

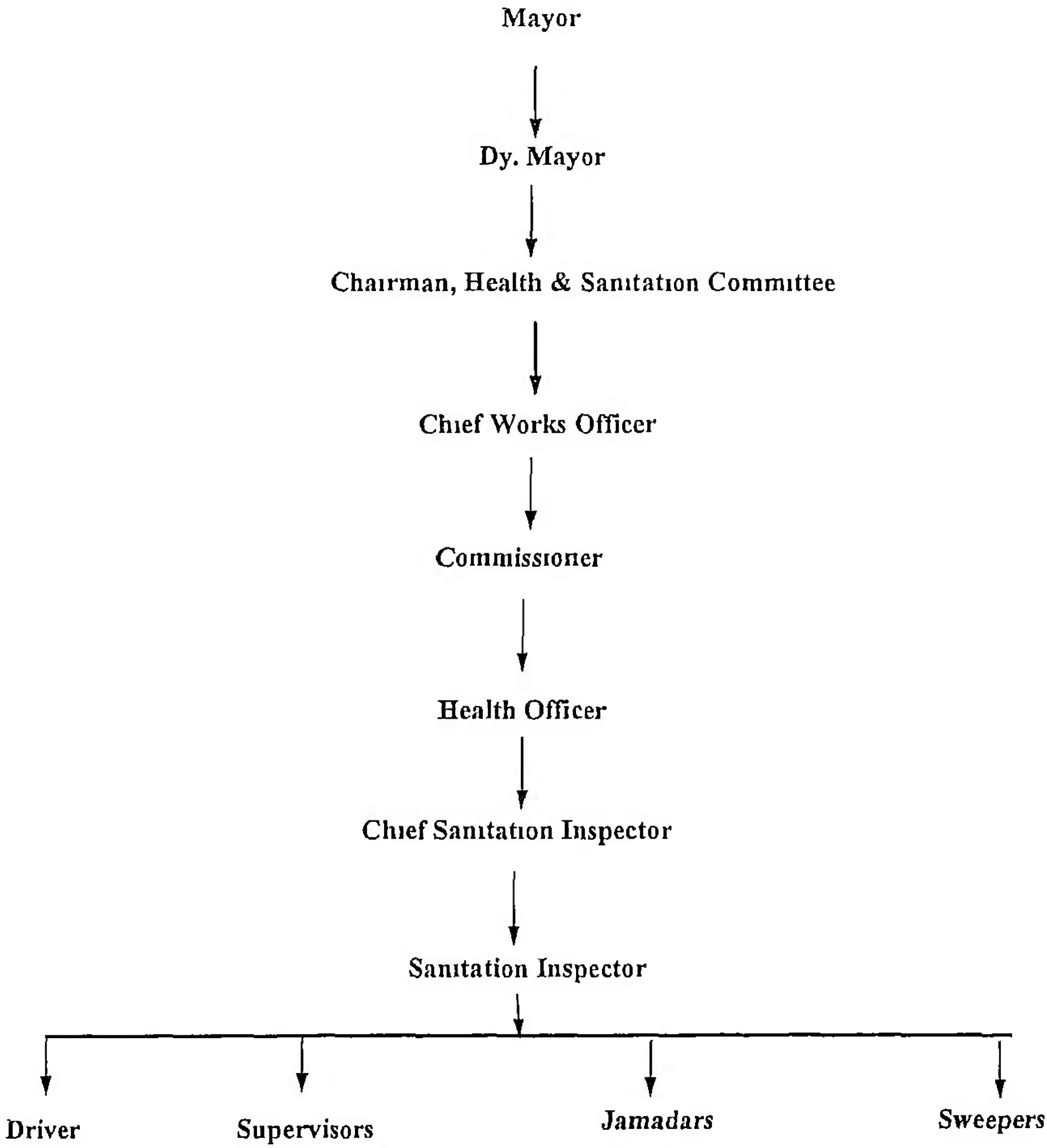

Figure 4.1 Organisational Structure of Municipal Corporation, Jaipur

As far as the collection of garbage by the generator at fixed places is concerned, the public co-operation is minimum They throw the garbage out of their properties onto streets/roads creating an ugly sight, part of the thrown refuse is eaten away by stray animals like cows, pigs, etc This is mainly due to the fact that there are only 292 bins provided by the Municipal Corporation in whole of the Jaipur city which are not sufficient for the storage of the waste generated

4.3.2 Transportation

Refuse collected at garbage collection depots is transported by Municipal Corporation The vehicles used for transportation are open tractors, dumpers, refuse collector multipack, front end loaders, etc On an average a vehicle makes 3-4 trips daily Average haulage is 15 Km Municipal Corporation spent Rs 147 44 per ton and paid to private contractors @ Rs 117 30 per ton for transportation in the financial year 1994-95 It spent Rs 118 25 per capita/year for transportation of the waste during the financial year 1994-95 The waste is almost always transported in uncovered vehicles, some times covered by a plastic sheet Waste keeps spilling off throughout the way to dumping site

4.3.3 Disposal

Previously the refuse used to be dumped at Jagatpura compost plant Now a days this plant is abandoned on the premise that the residential colony around it has been developed completely Presently the entire solid waste of Jaipur

city is dumped at Gopalpura, 15 Km from the city, for reclaiming the depression Waste disposal is by land filling After the waste is dumped, it is levelled but neither compacted nor covered by soil layer Then various pesticides are sprayed over it

4.3.4 Recovery

No efforts are made by Municipal Corporation for any kind of resource recovery but ragpickers are doing this job very efficiently Approximately 40,000-60,000 ragpickers are involved in segregation of various resources out of the solid waste of Jaipur city Average income of a ragpicker is Rs 30-50 daily Various materials collected by them are

i Paper
ii Polythene & Plastic
iii Glass
iv Metal
v Rubber

There are approximately 2000 dealers who buy these materials from ragpickers and then sell to interested buyers Average monthly collection of various recyclable material at a dealers shop is given in Table 4 2

Table 4.2 Average Monthly Collection of Recyclable Materials at a Dealer's Shop

Material	*Items*	*Price Rs/Kg*	*Quantity 100Kg/month*	*Used At*	*Used For*
Paper	Newspaper	4 00	10	Jaipur	Fancy recycled paper, Cardboard
	Cardboard	2 50			
	Sweet boxes	1 60			
Plastics	Buckets, tubs	12 00	8-9	Delhi	
	Ghee tins			Delhi	
	Shoe soles	8 00			
	Milk bags	12 00	7-8	Delhi	
	Liquor bags	12 00	0 5-0 6	Delhi	
	Washing powder bags	9 00	4-5	Delhi	
	Ordinary carry bags	3 00	7-8	Jaipur	Pipes
Glass	Unbroken bottles	1 00-2 00*			Refilling
	Broken glass	1 25		Firozabad	Glass bangles
Metal	Nails, screws, springs, talcum powder tins,carbonated drink bottles' lids	5 25		Jaipur	Iron rods
Rubber	Slippers,	0 50			
	Tyres, tubes,	8 00	5-6	Delhi	
	Rubber soles				

* Rs per bottle

4.4 WASTE GENERATED

4.4.1 Sources

Municipal solid waste is a combination of waste from -

1 *Households*

2 Commercial/Community centers

3 Vegetable market

4 Hospitals

4.4.2 Quality

Quality of the waste depends upon the source of the waste Average composition of waste from different sources is shown in Figure 4 2 to 4 5 Organic carbon content of solid waste ranges between 0 17 to 9 86% and the moisture content between 4 33 to 17 24%

4.4.3 Quantum

The quantity of solid waste generated per capita per day in the urban areas in India has been reported to be 0 3 to 0 6 Kg In Jaipur per capita waste production is about 0 4 Kg a day The distribution of the solid waste generated from various sources is shown in Figure 4 7 Distribution of the quantity of different materials in the solid waste generated is shown in Figure 4.8

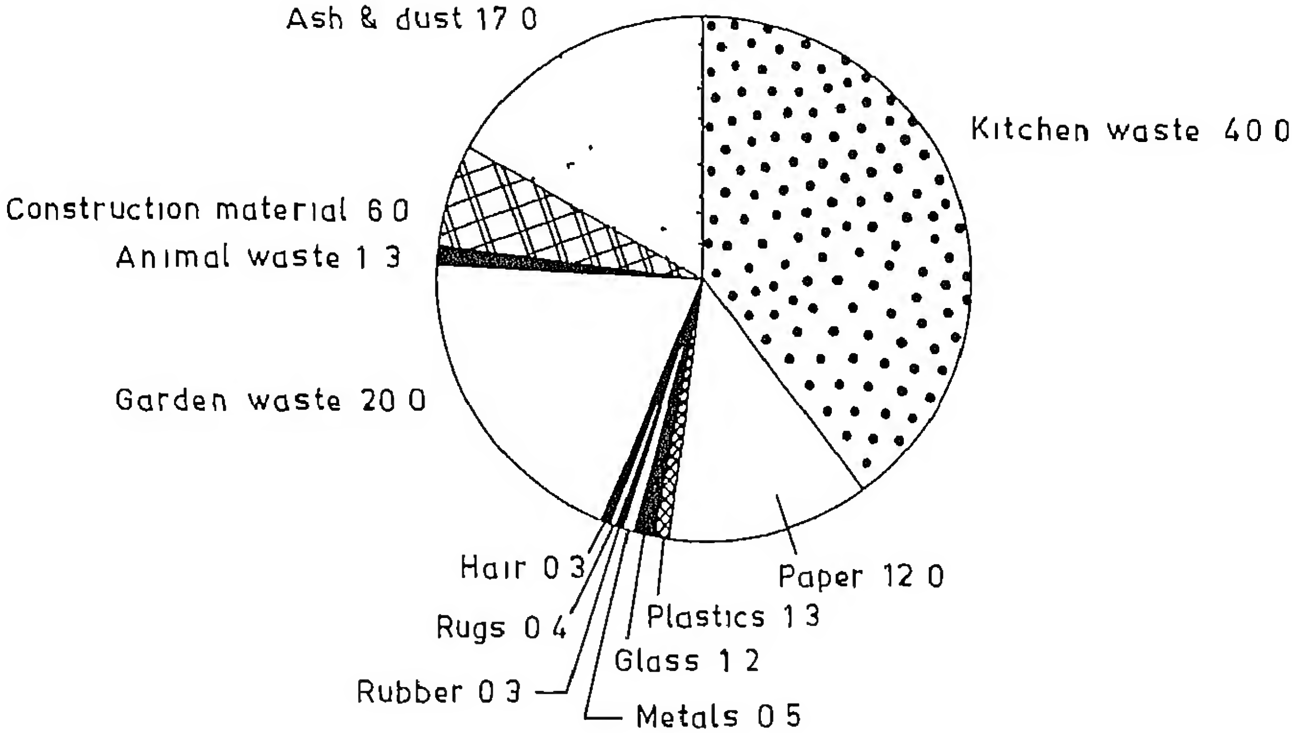

Figure 4.2: Average Percentage Composition of Houehold waste

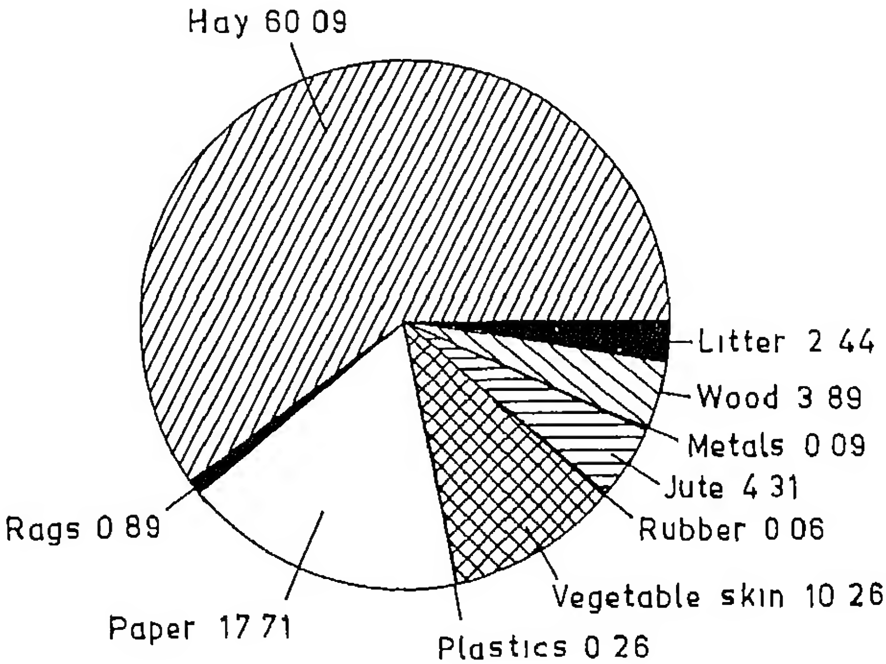

Figure 4.3 : Average Percentage Composition of Vegetable Market Waste

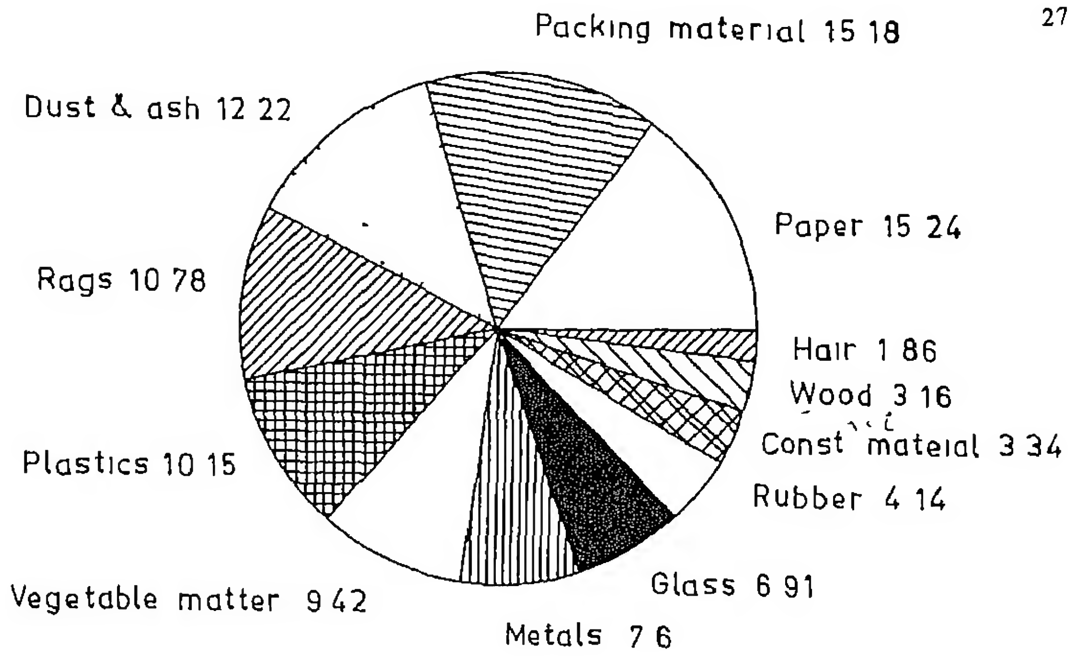

Figure 4.4: Average Percentage Composition of Community Centre Waste

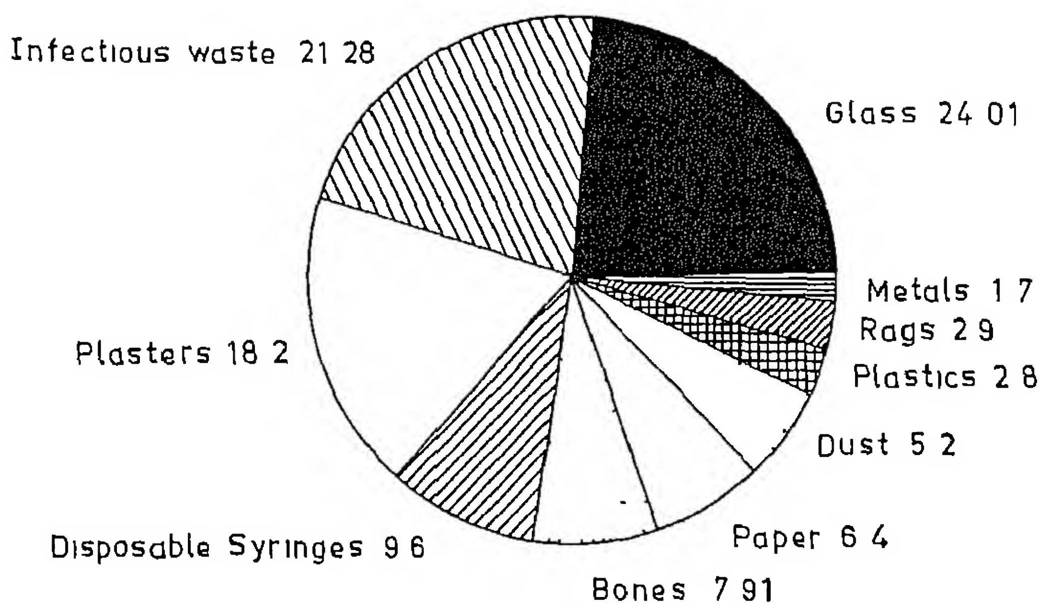

Figure 4.5 : Average Percentage Composition of Hospital Waste

4.5 WASTE COLLECTED & DISPOSED

Aveiage composition of the waste at dumping site, Gopalpura is shown in Figure 4 6 Average moisture content of the solid waste at dumping site is 20 9% and average organic carbon content is 2 94% Municipal Corporation along with private collectors collects and disposes only 75% of the waste generated Quantity of different materials present at dumping site are shown in Figuie 4 8

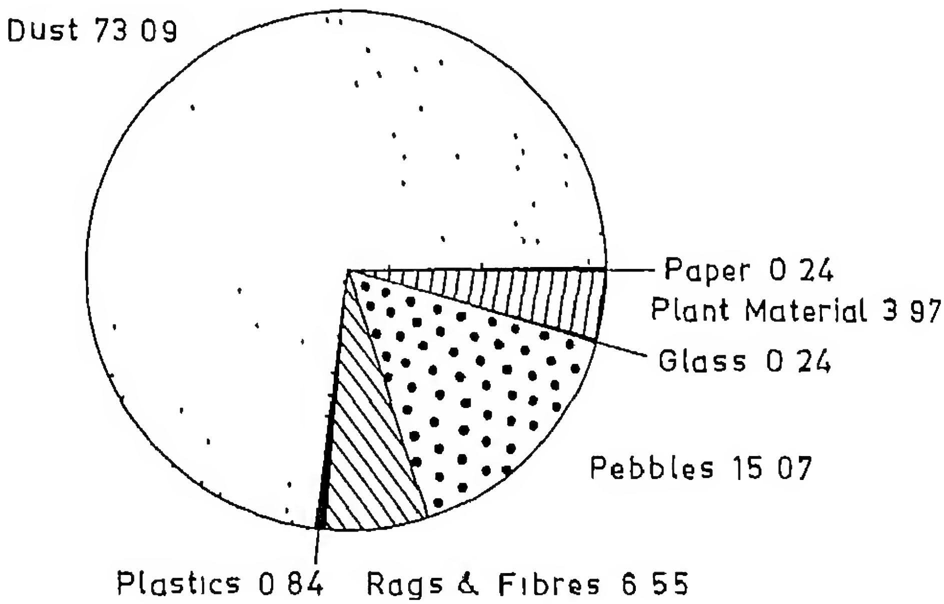

Figure 4.6 : Average Percentage Composition of Waste at Dumping Site

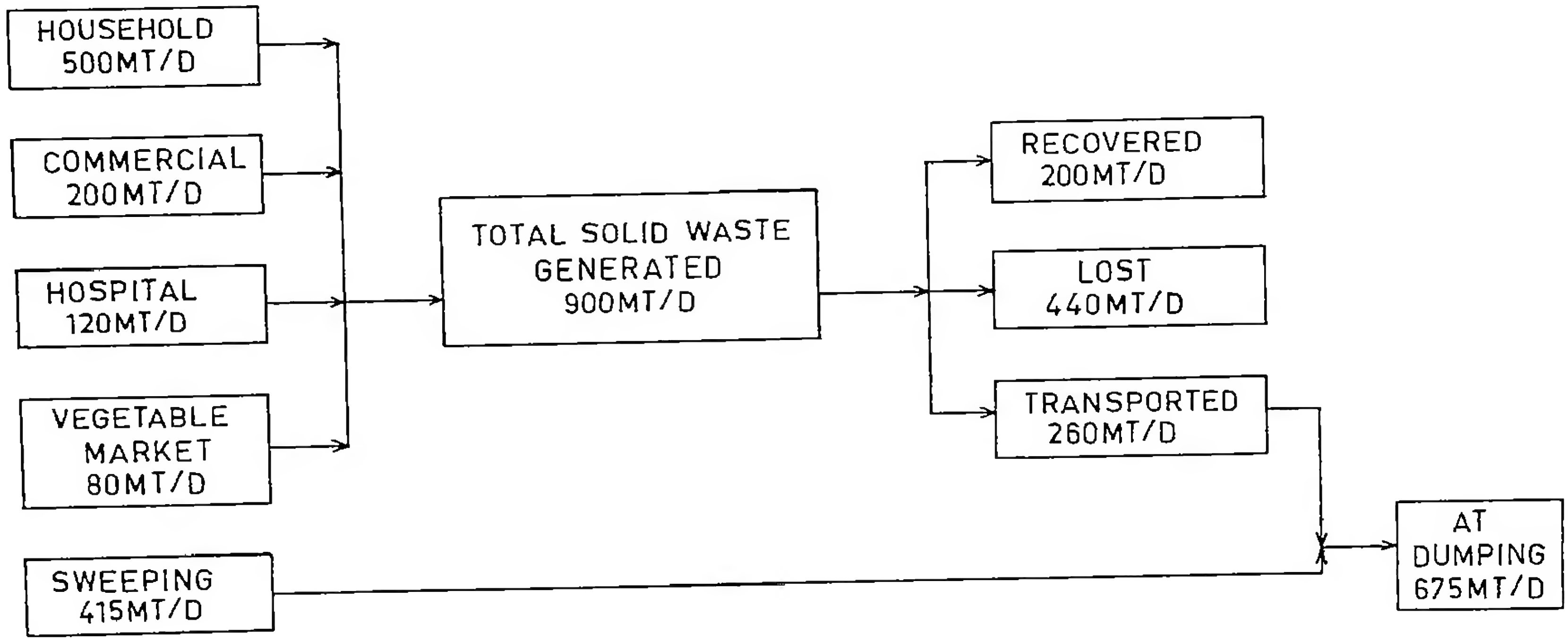

Figure 4.7: Mass Balance of Waste Generated

4.6 LOSSES

By applying the following equation for mass balance of various recyclable/reusable materials, it was found that substantial amount of paper and potential soil conditioners get lost between generation to disposal of the waste Mass balance of different materials is shown in Figure 4 8

$$Q_G = Q_D + Q_R + Q_L$$

Q_G = Quantity generated

Q_D = Quantity at dumping site

Q_R = Quantity recovered

Q_L = Quantity lost

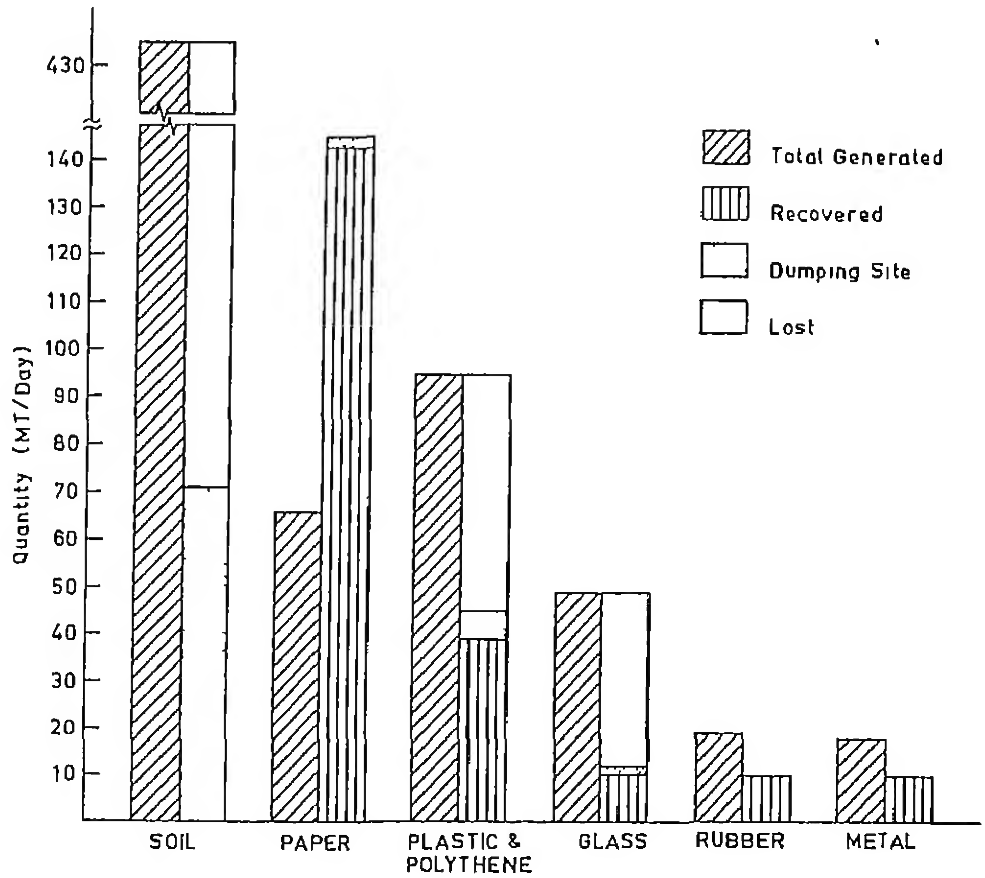

Figure 4.8: Fate of Various Constituents in Solid Waste.

5. APPLICATION OF THE ANALYTIC HIERARCHY PROCESS FOR RANKING SOLID WASTE MANAGEMENT PRACTICE

5.1 THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a methodology to systematically evaluate, often conflicting criteria It is a relatively new addition to the family of multi-attribute decision models and was developed by Saaty (1980) Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyse judgments through a process of determining the relative importance of a set of activities or criteria The methodology is based on the concept of *trade-off* and enables the decision-maker to develop the trade-off implicitly in the course of structuring and analysing a series of reciprocal pair-wise comparison matrices

The AHP can be succinctly summarised in terms of its three principal components First, the principal problem is decomposed into a hierarchy Each level of hierarchy consists of a set of elements and each element, in turn, is broken into sub-elements for the next level of the hierarchy The final level consists of the specific courses of action that are being contemplated for adoption Structuring any problem hierarchically is an efficient and intuitive

way of dealing with the complexity and identifying the relevant components of the problem (Srinivasan and Kim, 1989)

Second, within each hierarchical level, relative weights for the various elements are established using a measurement methodology Use of the methodology requires the decision-maker to evaluate the elements in a particular level in a pair-wise fashion using a 9- point scale shown in Table 5 1 The pair-wise comparisons indicate the degree to which one element dominates another element of the same level, with respect to each element of the preceding level

Third, the pair-wise comparison matrices are evaluated using a measurement theory The basic assumption underlying the measurement theory in the AHP is that relative dominance can be measured by pair-wise comparisons A pair-wise comparison of a set of n attributes can be conducted and their relative importance can be established as follows

If the attributes are denoted by O_1, O_2 ,O_n and their relative importance by w_1 ,w_2 , ... w_n , the pair-wise comparison matrix O may be expressed by the reciprocal matrix as shown below

$$
\begin{array}{ccccc}
 & O_1 & O_2 & . & O_n \\
O_1 & w_1/w_1 & w_1/w_2 & .. & w_1/w_n \\
O_2 & w_2/w_1 & w_2/w_2 & & w_2/w_n \\
 & & & . & \\
O_n & w_n/w_1 & w_n/w_2 & & w_n/w_n
\end{array}
$$

where w_i / w_j reflects the relative importance of element i over element j If O is multiplied by the transpose of the vector, $w^T \equiv (w_1, w_2, \quad, w_n)$ We obtain the vector nw and the problem takes the form:

$$Ow = nw \tag{5 1}$$

It is implicitly assumed, in the case above, that the weights, w, are known In case only O is known and the weights are to be recovered, the system ($O-nI)w=0$, needs to be solved for the unknown w This has a non-zero solution if and only if n is an eigen-value of O, i e it is a root of the characteristic equation of O But O has a unit rank since every row of O is a constant multiple of the first row Thus, all the eigen values, λ_i, $i = 1,2, \quad, n$, of O are 0 except one (Kreyszig, 1983) It is also known that

$$\sum_{i=1}^{n} \lambda_i = trace(O) = sum\ of\ the\ diagonal\ elements = n$$

Therefore, only one of the λ_i λ_{max} (the maximum eigen value), equals n and all the other $\lambda_i = 0$ The solution w of the above eigen value problem is any column of O These solutions differ by a multiplicative constant However, for operational reasons, it is desirable to normalise the solution so that the weights sum to unity The result is a unique solution regardless of which column is used

The matrix O satisfies the *cardinal consistency* property $O_{ij}\ O_{jk} = O_{ik}$ Thus, given any row of O, the rest of the entries can be determined from this

relation However, the scale w is unknown and thus, only the estimates of the ratios in the matrix can be made In this case, the cardinal consistency relation need not hold, nor need an *ordinal transitivity* relation of the form $O_i > O_j$, $\cap O_j \Rightarrow O_j > O_k$ (where, O_i are the rows of O) Since qualitative judgement remains inconsistent and intransitive, despite best efforts, the inconsistency in the comparison data needs to be considered It can be shown in any matrix, that small changes in the coefficients implies small changes in the eigen values It is also known from the Perron-Frobenius theorem, that a matrix of positive elements has a real positive eigen value whose modulus exceeds those of all other eigen values (Encyclopedia of Mathematics, 1985) The problem $Ow = nw$, can thus be transformed to $O' w' = \lambda_{max} w'$, where, O' represents the matrix, which does not satisfy the cardinal consistency property, λ_{max} The maximum eigenvalue of matrix O' and w' the corresponding eigenvector solution is unique when normalised

The question that comes up then is how close, in such cases, is λ_{max} to n and w' to w Saaty (1980) has shown that for all possible states and that $(\lambda_{max} - n)/(n-l)$ serves as an index measure of consistency The index indicates the departure from consistency of the comparison ratio, w_i/w_j, and the ratios are deemed consistent, if $\lambda_{max} = n$ Saaty (1986) has established, for different order random entry reciprocal matrices, an average consistency index which ranges from 0 for 1 to 2 element matrices, to 0 9 for 4 element matrices and 1 49 for 10 element matrices

Thus, the pair-wise comparison matrix O is used to elicit the judgement of decision-makers or a group of experts with regards to the relative importance of a set of attributes for each element of the preceding level The principle

eigenvector (corresponding to the maximum eigen value) is then extracted and normalised to yield local priorities for the elements of the matrix Several methods can be used for deriving priority vectors from pair-wise reciprocal comparison matrices Fichtner (1986) carried out a comparative analysis of the various methods Saaty (1980) advocates the use of the principle eigenvector method The method proposed by Saaty (1980) for the calculation of the eigenvector elements is given in Section 5 5 Local priorities are then transformed to global priorities by weighting them with the global priorities of the elements of the preceding level Continuing this process of eigenvector extraction and weighting through the levels of the hierarchy leads to a uni-dimensional priority (weight) scale for the elements in the final level An illustration of this process is given by Srinivasan and Kim (1989) For the present study, this process was applied, the details of which are given in following sections

For the present study, the spatial -AHP technique, developed by Siddiqui *et al* (1996), was applied to rank potential practice for solid waste disposal The AHP decision making methods, as used in spatial-AHP involves the following five steps (Siddiqui *et al*, 1996) (1) identifying the decision factors associated with the problem, (2) structuring them in a decision hierarchy, (3) judging the relative importance of the decision-hierarchy elements, (4) aggregating these measures in order to calculate a suitability index of the alternatives, (5) ranking according to the suitability indices. These steps are described subsequently.

Table No.5.1: Analytic Hierarchy Measurement Scale
(Srinivasan and Kim, 1989)

Reciprocal Measure of intensity of Importance	*Definition*	*Explanation*
• 1	Equal importance	Two activities contribute equally to the objective
• 3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
• 5	Essential or strong importance	Experience and judgement strongly favour one activity over another
• 7	Demonstrated importance	An activity is strongly favoured and it's dominance is demonstrated in practice
• 9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
• 2,4,6,8	Intermediate values between two adjacent judgements	When compromise is needed
• Reciprocal of the above	If activity *i* has one of the above non zero numbers assigned to it when compared to activity *j*, then *j* has the reciprocal value when compared with *i*	

5.2 DECISION FACTORS

Decision factors are used to relate attributes to suitability concerning a particular goal as in this case, selecting a solid waste management practice to follow solid waste management consists of four components namely, collection, transportation, processing and disposal For the present study first two and the last two are grouped together and compared pairwise at level II of the hierarchy Then primary factors or decision criteria, which contribute significantly to these components of solid waste management practice are identified as economic viability, social impact, environmental considerations , etc Once, the primary decision criteria are selected, sub factors, and even sub-sub-factors are identified to better describe these criteria For instance economic viability can be categorised into resource recovery, capital cost, operating cost and the information about capital cost can be further grouped within selected ranges

5.3 DECISION HIERARCHY

The decision factors after being identified are arranged in a decision hierarchy A decisions hierarchy consists of a number of levels The top level is the goal of the hierarchy while the rest of the levels describe the factors and the sub factors in increasing details The lowest level contains the attributes

of each alternative proposal The construction of these levels are qualitative and depends on the decision maker's understanding of the problem

For the present study, the decision hierarchy used, is given in the schematic diagram in Figure 5 1 The range of values, that were used for some of the highest level parameters are based on the judgement Any other justified range of values can be used

Other reasonable decision hierarchy can be incorporated within the same framework For example, other decision factors can be used depending on the decision maker's perspective Data availability is of course a pre-requisite

4 5 EVALUATION OF DECISION FACTORS

The decision factors after being arranged in a decision hierarchy are evaluated by comparing the elements in a particular level in a pairwise fashion using a 9- point scale as shown in Table 5 1 Following are some of the criteria taken into account while evaluating the elements-

Level I	*Level II*	*Level III*	*Level IV*	*Level V*	*Level VI*
				Paper	0 - 10% >10 - 40% >40 - 70% >70%
				Plastics & Polythene	0 - 10% >10 - 40% >40 - 70% >70%
			Resource Recovery	Metal	0 - 30% >30 - 60% >60%
		Economics		Glass	0 - 30% >30 - 60% >60%
	Collection and Transportation			Rubber	0 - 40% >40 - 70% >70%
				Soil Conditioners	0 - 30% >30 - 60% >60%
			Operating Cost	≤Rs 10[#] >Rs 10-Rs 15[#] > Rs 15[#]	
			Capital cost	≤ Rs 1* >Rs 1-Rs 2* >Rs 2*	
			Employment	Increase No change Decrease	
Solid Waste Management Practice		Social aspect	Child labour	Discouraged Compromised Encouraged	
			Health of the workers	No adverse effect Marginal adverse effect Acute adverse effect	
			Participation by generator	Direct Indirect None	
			Health of the citizens	No adverse effect Marginal adverse effect Acute adverse effect	
				Air	Low Moderate Extreme *[Contd]*

Level I	*Level II*	*Level III*	*Level IV*	*Level V*	*Level VI*
Solid Waste Management Practice		Environmental considerations	Pollution	Water	Low Moderate Extreme
				Land	Low Moderate Extreme
			Aesthetics	Positive effect No effect Negative effect	
			Stray animals	Discouraged No effect Encouraged	
	Processing & Disposal	Quality of Waste	% of degradable matter	0 - 30% >30 - 60% >60%	
			Moisture content	0 - 30% >30 - 60% >60%	
		Economics	Requirement of land Vs availability	Less/Plenty More/Plenty Less/Scare More/Scare Less/Very scare More/ Very scare	
			Returns/ Expenditure	<10% 10 - 30% >30 - 60% >60%	
		Environmental considerations	Water pollution	Low Moderate Extreme	
			Air pollution	Low Moderate Extreme	
			Land Pollution	Low Moderate Extreme	

* Per capita per year
\# Per capita per month

Figure 5 1 Schematics of the Decision Hierarchy Used for Ranking Solid Waste Management Options

1 Economics almost always rules any course of action

2 Resource recovery is an essential step towards suitable development

3 Operating cost is a much more frequent phenomenon than capital cost

4 Employment takes priority over any other factors in our poverty stricken country

5 Child labour is illegal

6 Humans are more tolerant towards an ugly sight (aesthetics) than bad odour (air pollution)

7 Stray animals may lead to health problem in society and also are proved to be traffic hazard

8 Recovery of paper is more important as it would result in resource (forest) saving indirectly and would help in maintaining ecological balance

9 Recovery of plastic/polythene is also equally important as it is not degradable by any of the natural processes

10 Glass recovery is important than rubber as glass manufacturing results in more pollution

11 Soil conditioners' recovery is the least important of all because even if not recovered, would not cause much harm

12 Collection of the waste is more important than processing as

(a) processing itself is dependent on collection

(b)city is clean when waste is just collected & dumped

without processing than when not collected at all

5.5 RELATIVE IMPORTANCE WEIGHTS

The RIWs are the normalised eigen vectors corresponding to the maximum eigen value of the pair wise comparison matrices constructed at each level of the decision hierarchy The RIW assigned to each hierarchy element is determined by normalising the eignvector of the decision matrix (Tables 5 2 to 5 37) Eigenvector values are estimated by multiplying all the elements in a row and taking the nth root of the product, where n is the number of row elements For example, for the first row in Table 5 3 where $n = 3$, the eigenvector value is given by $\sqrt[3]{1*3*4}$ or 2 289 Normalisation of eigenvector is accomplished by dividing each eigenvector element by the sum of the eigenvector elements of the decision matrix For the first row in Table 5 3, the RIW is given by 2 289/(2 289 + 1.186 + 0 368), or 0 597

The calculation of the RIWs are shown in Tables 5 2 to 5 37 where the weights are calculated for the different levels (levels II, III, IV, V & VI) of the decision hierarchy

5.6 SUITABILITY INDEX

The Suitability Index for each practice is determined by aggregating the Relative Importance Weight (RIWs) at each level of the hierarchy The

Suitability Indices are calculated by multiplying the RIW of an attribute by the RIW of the associated higher level factors, summing the values for all grouped elements, multiplying those sums by RIWs of the associated higher level factor and following this process recursively until the primary decision factors (level II in the hierarchy) are reached For the six level hierarchy as in the present study, the equation is as follows

$$SI = \sum_{i=1}^{N2}\left[RIW_i^2 \sum_{j=1}^{N3}\left\{RIW_{i,j}^3 \sum_{i,j,k}^{N4}\left(RIW_{i,j,k}^4 \sum_{i,j,k,l}^{N5}\left(RIW_{i,j,k,l}^5\left(RIW_{i,j,k,l,m}^6\right)\right)\right)\right\}\right]$$

where

SI = Suitability Index,

N2 = No of decision factors in level II

N3 = No of decision factors in level III

N4 = No of decision factors in level IV

N5 = No of decision factors in level V

RIW^2_i = RIW of level 2 decision factor i

$RIW^3_{i,j}$ = RIW of level 3 sub factor j, of level 2 decision factor i

$RIW^4_{i,j,k}$ = RIW of level 4 sub factor k, of sub factor j, of level 2 decision factor i

$RIW^5_{i,j,k,l}$ = RIW of level 5 sub factor l, of sub factor k, of sub factor j, of level 2 decision factor i

$RIW^6_{i,j,k,l,m}$ = RIW of level 6 sub factor m, of sub factor l, of sub factor k, of sub factor j, of level 2 decision factor i

5.7 SUITABILITY INDEX RANKING

After calculating the suitability index of each solid waste management practice, ranks are assigned by arranging the suitability indices in decreasing order Highest value of suitability index suggesting the best practice

Table 5.2 : RIW for Collection & Transportation and Processing & Disposal (λ_{max} = 2 0)

Level II Parameters → ↓	Collection & Transportation	Processing & Disposal	Estimated Eigen Element	RIW
Collection & Transportation	1	7	2 646	0 875
Processing & Disposal	1/7	1	0 378	0 125

Table 5.3 : RIW for Economics, Social Aspect & Environmental Considerations (λ_{max} = 3 196)

Level III Parameters → ↓	Economics	Social Aspects	Environmental Considerations	Estimated Eigen Element	RIW
Economics	1	3	4	2 289	0 597
Social Aspects	1/3	1	5	1 186	0 309
Env Considerations	1/4	1/5	1	0 368	0 096

Table 5.4 . RIW for Quality of Waste, Economics and Environment considerations (λ_{max} = 3 039)

Level III Parameters → ↓	Economics	Environmental Considerations	Quality of Waste	Estimated Eigen Element	RIW
Economics	1	3	5	2 466	0 637
Env Considerations	1/3	1	3	1 000	0 258
Quality of Waste	1/5	1/3	1	0 405	0 105

Table 5.5 : RIW for Resource Recovery, Operating Cost and Capital Cost (λ_{max} = 3 039)

Level IV Parameters → ↓	Resource Recovery	Operating Cost	Capital Cost	Estimated Eigen Element	RIW
Resource Recovery	1	3	5	2 466	0 637
Operating Cost	1/3	1	3	1 000	0 258
Capital Cost	1/5	1/3	1	0 405	0 105

Table 5.6 : RIW for Sub Factors of Social Aspects (λ_{max} = 4 456)

Level IV Parameters → ↓	Employment	Child Labour	Health of Workers	Patricipation of Generators	Estimated Eigen Element	RIW
Employment	1	3	7	4	3 027	0 554
Child Labour	1/3	1	2	5	1 351	0 247
Health of Workers	1/7	1/2	1	5	0 773	0 141
Patricipation of Generators	1/4	1/5	1/5	1	0 316	0 059

Table 5 7 : RIW for Sub Factors of Environmental Consideration (λ_{max} = 4 497)

Level IV Parameters → ↓	Health of Citizens	Pollution	Aesthetics	Stray Animals	Estimated Eigen Element	RIW
Health of Citizen	1	7	9	7	4 583	0 673
Pollution	1/7	1	5	5	1 374	0 202
Aesthetics	1/9	1/5	1	1/4	0 273	0 040
Stray Animal	1/7	1/5	4	1	0 581	0 085

Table 5.8(A) : RIW for Sub Factors of Quality of Waste for Biological Process (λ_{max} = 2 0)

Level IV Parameters → ↓	Percentage of degradable matter	Moisture content	Estimated Eigen Element	RIW
Percentage of degradable matter	1	7	2 646	0 875
Moisture content	1/7	1	0 378	0 125

Table 5.8(B) : RIW for Sub Factors of Quality of Waste for Incineration Process (λ_{max} =2 0)

Level IV Parameters → ↓	Percentage of degradable matter	Moisture content	Estimated Eigen Element	RIW
Percentage of degradable matter	1	1/ 5	0 447	0 167
Moisture content	5	1	2 236	0 833

Table 5 9 : RIW for Sub Factors of Economics for Processing and Disposal (λ_{max} = 2 0)

Level IV Parameters → ↓	Requirement of land Vs Availability	Returns / Expenditure	Estimated Eigen Element	RIW
Requirement of land Vs Availability	1	3	1 732	0 750
Returns / Expenditure	1/3	1	0 577	0 250

Table 5.10 : RIW for Sub Factors of Environmental Pollution (λ_{max} = 3 136)

Level IV Parameters → ↓	Water Pollution	Air Pollution	Land Pollution	Estimated Eigen Element	RIW
Water Pollution	1	3	5	2 466	0 617
Air Pollution	1/3	1	5	1 186	0 297
Land Pollution	1/5	1/5	1	0 342	0 086

Table 5 11 · RIW for Recovery of Various Resources (λ_{max} = 6 143)

Level V Parameters → ↓	Paper	Plastics	Metal	Glass	Rubber	Soil Conditioners	Estimated Eigen Element	RIW
Paper	1	1	7	7	7	9	3 816	0 387
Plastics	1	1	7	7	7	9	3 816	0 387
Metal	1/7	1/7	1	3	3	7	1 103	0 112
Glass	1/7	1/7	1/3	1	2	5	0 639	0 065
Rubber	1/7	1/7	1/3	1/2	1	3	0 466	0 047
Soil Conditioners	1/9	1/9	1/7	1/5	1/3	1	0 221	0 022

Table 5.12 : RIW for Different Ranges of Operating Cost (λ_{max} = 3 124)

Level V Parameters → ↓	< Rs 10 / capita / month	Rs 10 - < Rs 15 / capita / month	> Rs 15 / capita / month	Estimated Eigen Element	RIW
< Rs10 / capita /month	1	4	7	3 036	0 687
Rs 10 - < Rs 15 / capita / month	1/4	1	5	1 077	0 244
> Rs 15 /capita /month	1/7	1/5	1	0 306	0 069

Table 5.13 : RIW for Different Ranges of Capital Cost (λ_{max} = 3 217)

Level V Parameters → ↓	< Rs 1 / capita / year	Rs 1 - < Rs 2 / capita / year	> Rs 2 / capita / year	Estimated Eigen Element	RIW
< Rs1 / capita / year	1	4	5	2 714	0 657
Rs 1 - < Rs 2 / capita / year	1/4	1	5	1 077	0 261
> Rs 2 /capita / year	1/5	1/5	1	0 342	0 083

Table 5 14 : RIW for Effect on Employment (λ_{max} = 3 233)

Level V Parameters → ↓	Increase	No Change	Decrease	Estimated Eigen Element	RIW
Increase	1	3	5	2 466	0 602
No Change	1/3	1	7	1 326	0 324
Decrease	1/5	1/7	1	0 306	0 075

Table 5 15 : RIW for Effect on Child Labour (λ_{max} = 3 117)

Level V Parameters → ↓	Discouraged	Compromised	Encouraged	Estimated Eigen Element	RIW
Discouraged	1	5	9	3 557	0 735
Compromised	1/5	1	5	1 000	0 207
Encouraged	1/9	1/5	1	0 281	0 058

Table 5.16 . RIW for Effect on Health of the Workers (λ_{max} = 3 208)

Level V Parameters → ↓	No Adverse Effect	Marginal Adverse Effect	Acute Adverse Effect	Estimated Eigen Element	RIW
No Adverse Effect	1	5	9	3 557	0 722
Marginal Adverse Effect	1/5	1	7	1 119	0 227
Acute Adverse Effect	1/9	1/7	1	0 251	0 051

Table 5.17 : RIW for Kind of Participation of Generator (λ_{max} = 3 123)

Level V Parameters → ↓	Direct	Indirect	None	Estimated Eigen Element	RIW
Direct	1	4	7	3 037	0 687
Indirect	1/4	1	5	1 077	0 722
None	1/7	1/5	1	0 306	0 244

Table 5.18 · RIW for Effect on Health of the Citizens (λ_{max} = 3 208)

Level V Parameters → ↓	No Adverse Effect	Marginal Adverse Effect	Acute Adverse Effect	Estimated Eigen Element	RIW
No Adverse Effect	1	5	9	3 557	0 722
Marginal Adverse Effect	1/5	1	7	1 119	0 227
Acute Adverse Effect	1/9	1/7	1	0 251	0 051

Table5.19 : RIW for Sub Factors of Pollution (λ_{max} =3 136)

Level V Parameters → ↓	Air	Water	Land	Estimated Eigen Element	RIW
Air	1	4	8	3 175	0 691
Water	1/4	1	6	1 145	0 249
Land	1/8	1/6	1	0 275	0 060

Table 5.20 : RIW for Effect on Aesthetics (λ_{max} = 3.208)

Level V Parameters → ↓	Positive Effect	No Effect	Negative Effect	Estimated Eigen Element	RIW
Positive Effect	1	5	9	3 557	0 722
No Effect	1/5	1	7	1 119	0 227
Negative Effect	1/9	1/7	1	0 251	0 057

Table 5 21 RIW for Effect on Population of Stray Animals (λ_{max} = 3 208

Level V Parameters → ↓	Discouraged	No Effect	Encouraged	Estimated Eigen Element	RIW
Discouraged	1	7	9	3 979	0 772
No Effect	1/7	1	5	0 894	0 173
Encouraged	1/9	1/5	1	0 281	0 054

Table 5.22 . RIW for Percentage of Degradable Matter (λ_{max} = 3 197)

Level V Parameters → ↓	0-30%	>30-60%	>60%	Estimated Eigen Element	RIW
0-30%	1	1/6	1/8	0 275	0 058
>30-60%	6	1	1/5	1 063	0 224
>60%	8	5	1	3 412	0 718

Table 5 23(A) · RIW for Moisture Content for Biological Process (λ_{max} = 3 218)

Level V Parameters → ↓	0-30%	>30-60%	>60%	Estimated Eigen Element	RIW
0-30%	1	1/5	4	0 928	0 220
>30-60%	5	1	5	2 924	0 693
>60%	1/4	1/5	1	0 368	0 087

Table 5.23(B) . RIW for Moisture Content for Incineration Process (λ_{max} = 3 183)

Level V Parameters → ↓	0-30%	>30-60%	>60%	Estimated Eigen Element	RIW
0-30%	1	5	7	3 271	0 715
>30-60%	1/5	1	5	1 000	0 218
>60%	1/7	1/5	1	0 306	0 067

Table 5 24 · RIW for Requirement of Land V/s Availability (λ_{max} = 6 446)

Level V Parameters → ↓	Less / Plenty	More / Plenty	Less / Scarce	More / Scarce	Less / Very scarce	More / Very scarce	Estimated Eigen Element	RIW
Less / Plenty	1	2	5	7	8	9	4 141	0 432
More / Plenty	1/2	1	2	5	7	9	2 608	0 272
Less / Scarce	1/5	1/2	1	5	5	7	1 611	0 168
More / Scarce	1/7	1/5	1/5	1	1	4	0 504	0 053
Less / Very Scarce	1/8	1/7	1/5	1	1	5	0 511	0 053
More / Very	1/9	1/9	1/7	1/4	1/5	1	0 211	0 022

Table 5 25 RIW for Returns / Expenditure (λ_{max} = 4 364)

Level V Parameters → ↓	< 10%	10 - 30%	> 30 - 60%	> 60%	Estimated Eigen Element	RIW
< 10%	1	1/3	1/5	1/7	0 312	0 050
10 - 30%	3	1	1/5	1/7	0 541	0 086
> 30 - 60%	5	5	1	1/5	1 495	0 237
> 60%	7	7	x 5	1	3 956	0 628

Table 5 26 RIW for Levels of Water Pollution (λ_{max} = 3 182)

Level V Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	5	7	3 271	0 715
Moderate	1/5	1	5	1 000	0 218
Extreme	1/7	1/5	1	0 306	0 067

Table 5.27 RIW for Levels of Air Pollution (λ_{max} = 3 208)

Level V Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	5	9	3 557	0 728
Moderate	1/5	1	7	1 118	0 227
Extreme	1/9	1/7	1	0 251	0 051

Table 5.28 . RIW for Levels of Land Pollution (λ_{max} = 3 073)

Level V Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	3	4	2 289	0 614
Moderate	1/3	1	3	1 000	0 268
Extreme	1/4	1/3	1	0 437	0 117

Table 5.29 . RIW for Paper Recovery (λ_{max} = 4 449)

Level VI Parameters → ↓	0 - 10%	> 10 - 40 %	> 40 - 70 %	> 70 %	Estimated Eigen Element	RIW
0 - 10%	1	1/5	1/7	1/9	0 237	0 035
> 10 - 40 %	5	1	1/5	1/7	0 615	0 092
> 40 - 70 %	7	5	1	1/5	1 627	0 243
> 70 %	9	7	5	1	4 213	0 630

Table 5 30 : RIW for Plastic Recovery (λ_{max} = 4 449)

Level VI Parameters → ↓	0 - 10%	> 10 - 40 %	> 40 - 70 %	> 70 %	Estimated Eigen Element	RIW
0 - 10%	1	1/5	1/7	1/9	0 237	0 035
> 10 - 40 %	5	1	1/5	1/7	0 615	0 092
> 40 - 70 %	7	5	1	1/5	1 627	0 243
> 70 %	9	7	5	1	4 213	0 630

Table 5 31 RIW for Metal Recovery (λ_{max} = 3 183)

Level VI Parameters → ↓	0 - 30%	> 30 - 60%	> 60%	Estimated Eigen Element	RIW
0 - 30%	1	1/5	1/7	0 306	0 067
> 30 - 60%	5	1	1/5	1 000	0 219
> 60%	7	5	1	3 267	0 714

Table 5 32 : RIW for Glass Recovery (λ_{max} = 3 038)

Level VI Parameters → ↓	0 - 30%	> 30 - 60%	> 60%	Estimated Eigen Element	RIW
0 - 30%	1	1/3	1/5	0 405	0 105
> 30 - 60%	3	1	1/3	1 000	0 258
> 60%	5	3	1	2 467	0 637

Table 5.33 . RIW for Rubber Recovery (λ_{max} = 3 038)

Level VI Parameters → ↓	0 - 40%	> 40 - 70%	> 70%	Estimated Eigen Element	RIW
0 - 40%	1	1/3	1/5	0 405	0 105
> 40 - 70%	3	1	1/3	1 000	0 258
> 70%	5	3	1	2 467	0 637

Table 5 34 . RIW for Soil Conditioners Recovery (λ_{max} = 3 146)

Level VI Parameters → ↓	0 - 30%	> 30 - 60%	> 60%	Estimated Eigen Element	RIW
0 - 30%	1	1/5	1/8	0 292	0 062
> 30 - 60%	5	1	1/5	1 000	0 212
> 60%	8	5	1	3 420	0 726

Table 5 35   RIW for Levels of Air Pollution (λ_{max} = 3 182)

Level VI Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	5	7	3 271	0 715
Moderate	1/5	1	5	1 000	0 218
Extreme	1/7	1/5	1	0 306	0 067

Table 5 36 . RIW for Levels of Water Pollution (λ_{max} = 3 208)

Level VI Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	5	9	3 557	0 728
Moderate	1/5	1	7	1 118	0 227
Extreme	1/9	1/7	1	0 251	0 051

Table 5.37   RIW for Levels of Land Pollution (λ_{max} = 3 073)

Level VI Parameters → ↓	Low	Moderate	Extreme	Estimated Eigen Element	RIW
Low	1	3	4	2 289	0 614
Moderate	1/3	1	3	1 000	0 268
Extreme	1/4	1/3	1	0 437	0 117

6. EPILOGUE

The genesis for initiating the investigation reported in this thesis was the concern for hazardous conditions commonly prevailing in most of the rapidly growing urban centers, particularly in India, due to generation of large quantities of solid wastes from different sources as a result of various kind of activities As such the principal objective of the study was to analyse the problems associated with handling of solid wastes in urban centers and to suggest an approach for solid waste management practice

A preliminary study of literature on practice of solid waste handling in most of the Indian urban centers revealed that the issues related with various aspect of solid waste management are similar Hence it was considered appropriate to choose a typical urban center in order to identify and analyse the factors associated with generation, collection, storage, transfer, transport, characterization, processing, reuse, final disposal and environmental impact of solid wastes Jaipur city was chosen as a typical urban center to represent most of the Indian cities

Based on the analysis of the information collected on (i) the practice of solid waste collection, storage, transfer, transport and disposal, (ii) characteristics of solid waste at different stages of handling, viz generation, intermediate

storage, final disposal, etc through physical and chemical analysis, (iii) economic aspects in relation to expenditure on various operations, (iv) dependence directly or indirectly on employment, (v) attitude of the generator and (vi) social and some other environmental considerations, following conclusions could be made

- The characteristics of the solid waste changes significantly through various stages from generation to final disposal
- Most of the recyclable/reusable materials from solid wastes are separated in an environmentally unsound and socially unacceptable manner
- The value of the recyclable/reusable materials could increase substantially if provision is made for their separation at the generation point
- The solid waste reaching the final processing or dumping point is not amicable for any of the well established methods of processing and/or disposal and hence state of the art technologies for processing is of little value if collection and separation practices are inadequate
- While the percentage of recyclable/reusable material at the final disposal point is insignificant from economic point of view, the levels of such materials are high enough to cause degradation of environment, viz water, air and land pollution
- Most of the constituents which could be of any value are either picked up by ragpickers or eaten away by stray animals leading to their proliferation in a city
- Almost 40,000 - 60,000 ragpickers (out of city population of about 22,00,000) are involved and atleast one third of them are children

- Generators of solid wastes are indifferent to the practice of solid waste handling, probably because of very little efforts, both in terms of providing system that will involve them in proper storage and separation at the source and lack of concern/education towards environmental problems

After the above mentioned findings of the case study, that a proper storage and collection practice is absolutely necessary for a processing and disposal system to run efficiently and that solid waste management involves not only technology and economics but social and environmental aspect also, a methodology was developed to rank solid waste management alternatives adaptable to local conditions, taking into account all aspects related to solid waste management and finally reaching to an optimum trade off between all decision factors For development of methodology Analytical Hierarchy Process (AHP) was used A comprehensive description of AHP has been provided The methodology has been illustrated by (i) identifying the decision factors associated with the problem, (ii) structuring them in a decision hierarchy (iii) judging the relative importance of the decision hierarchy elements and (iv) aggregating these measures in order to calculate a suitability index of alternatives For this the relevant information and experience of the study on Jaipur city has been used As the characteristics of solid waste have a fluctuating nature due to seasonal variations, variations in the economic status of the generators, their habits and also because of non homogeneity, it is quite difficult if not impossible to get consistent information on quality parameters of solid waste Quantity assessment is equally challenging and so for both an average approach was adopted While selecting the decision factors and comparing them at same level of hierarchy, subjectivity was

introduced Also while deciding the ranges for capital and operational costs in the V level of hierarchy, certain assumption were made A detailed questionnaire could be sent to experts in various fields associated with solid waste management and based on the response comparative evaluation of different elements could be done and new factors can also be introduced to make the method more elaborate Design of different storage and collection systems could be undertaken inclusive of design of storage bins, transportation vehicles with loading and unloading facilities and requirement of labour for developing labour intensive but simple and hygienic system for collection and segregation which will also be of interest to the generators of solid wastes

REFERENCES

Bhawalkar, U S , 1995, *Vermiculture Bioconversion of Organic Residues*, Ph D Dissertation, I I T Bombay

CPCB, 1994, *Management of Municipal Solid Wastes - Status and Options*, Central pollution Control Board, New Delhi

Chaudhary V , 1989, *A Study of Solid Waste Disposal of Jaipur City*, Ph D Dissertation, University of Rajasthan, Jaipur

Fichtner, J , 1986, On Deriving Priority Vectors from Matrices of Pairwise Comparison, Socio-Economic Planning Sciences, 20 (6)

Harrison, M C , 1983, 'Transfer and Carriage of Solid Waste', In *Practical waste Management*, Holmes, J R (Ed), John Wiley & Sons, New York

Higginson, A E , 1983, 'The Storage and Collection of Solid Waste', In *Practical waste Management*, Holmes, J R (Ed), John Wiley & Sons, New York

Mackenzie, L D and Cornwell, D A , 1991, 'Solid Waste Management' In *Introduction to Environmental Engineering*, McGraw Hill, New York

Nathawat, G S , 1994, *Solid Waste, Its Composition, Disposal, and Recycling. A Case Study of Jaipur City*, Report, Indira Gandhi Center for Human Ecology, Environmental and Pollution Studies, University of Rajasthan, Jaipur

Nath, K J , 1984, *Metropolitan Solid Waste Management in India*

Report of Committee on Urban Waste, 1975, Ministry of Works and Housing, Government of India

Saaty, T L , 1980, *The Analytical Hierarchy Process*, McGraw Hill, New York

Saaty, T L , 1986, Axiomatic Foundations of the Analytic Hierarchy Process, Management Science, July

Skitt, J , 1979, *Waste Disposal Management and Practice*, Charles Knight & Company Limited, London

Srinivasan, V and Y H Kim, 1989, Financial Application of the Analytic Hierarchy process, Proceedings of the International Conference on Multiple Criteria Decision Making Application in Industry and Service, Asian Institute of Technology, Bangkok

Tchobanoglous, G, H Theisen and R Eliassen, 1977, *Solid Wastes Engineering Principles and Management Issues*, McGraw Hill, New York

WHO Technical Report, 1984, In *Management of Solid Wastes in Developing Countries*, Flintoff, F (Ed), World Health Organisation, S-EA Series

Date Slip

This book is to be returned on the date last stamped